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The Deep Black Sea: Observability and Modality Afloat

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ABSTRACT

In the spirit of B. C. van Fraassen's view of science called *Constructive Empiricism*, we propose a scientific criterion to decide whether a concrete object is *observable*, as well as a coextensive scientific-philosophical definition of observability, and we sketch a rigorous account of modal language occurring in science. We claim that our account of observability solves three problems to which current accounts of observability, notably van Fraassen's own accounts, give rise. We further claim that our account of modal propositions (subjunctive conditionals included), which proceeds wholly within the framework of the semantic view on scientific theories, grounds his claim that such an account is possible without relying on 'inflationary metaphysics', notably without *postulating* an infinitude of different universes besides the universe we inhabit. We thus claim to solve a fourth problem: how to give a precise nominalist account of modal language in science tailor-made for Constructive Empiricism.

1 Introduction: Rough Guides

Preamble. In this Introduction we set the stage by reviewing a recent dialectic which is taking place, partly and prominently, in this journal concerning B. C. van Fraassen's epoch-making and passionately debated view of science called *Constructive Empiricism* (CE), a view propounded in van Fraassen ([1980], [1985], [1994], [2001], [2003]). The subject of the

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dialectic is the connexion between the concepts of *observability* and *modality*.[1] Within the confines of CE, their connexion stands in need of attention, because J. Ladyman discovered a tension between observability and modality so strong that it renders CE 'untenable as a philosophy of science' ([2000], p. 855). When our brief review of the recent dialectic is finished, we present, at the end of this Introduction, a preview of this paper and a statement of what it hopes to contribute to the extant literature.

The Rough Guide. The two distinctions between (I) *observable* and *unobservable* concrete objects, and between (II) *extensional* and *intensional*, in particular *modal*, language in science are of crucial importance for the realism-debate.[2] This is because whereas Realists defend that scientific knowledge includes, besides knowledge of actual *observables*, also knowledge of actual *unobservables* such as viruses, atoms, black holes and electromagnetic fields, Anti-Realists beg to disagree; and because whereas most if not all Realists defend that scientific knowledge includes, besides knowledge of what is *actual*, also knowledge of what is *possible*, what is *contingent*, what is *necessary* and of what *would*, or *might*, happen if so-and-so *were* the case, Anti-Realists, again, beg to disagree as soon as these modal notions are supposed to be more than utterances *flatus vocis*. For CE, *scientific knowledge* is exclusively about actual observables; of what CE *accepts*, exactly the part which is about actual observables only is thought to be *true*; with regard to what is left, a neutral attitude is deemed the right epistemic propositional attitude.[3] This is the *epistemic policy* of CE.

Although distinct, distinctions I and II seem tightly connected, because surely we have the following material (if not logical) equivalences: a DNA-molecule is unobservable iff it is *impossible* to observe it, and a living Tyrannosaurs rex is observable iff any (non-blind) person *would* see the creature if he *were* to stand in a typical Jurassic landscape, right in front of the reptile in broad daylight with his eyes wide open. Therefore, either the concept of observability and modal concepts are all *epistemic* or they are all *pragmatic*.[4] This means that a view of science like CE suffers from a

[1] Besides propositions that include the familiar modal notions of possibility, contingency and necessity, we also count subjunctive conditionals among modal propositions. Like Quine, we take *propositions* to be classes of logically equivalent *statements* (declarative sentences); then every two statements which belong to the same proposition are either both true or both false—or both indeterminate if *tertium datur*. For the sake of convenience, we sometimes confuse 'statement' and 'proposition'.

[2] All *abstract objects*, such as concepts, propositions, sets, functions and numbers, are by default unobservable. In this paper, *object* always means 'concrete (= non-abstract) object' unless specifically stated otherwise. Nothing in this paper depends on taking the distinction between concrete and abstract objects to be sharp or vague.

[3] van Fraassen ([1980], pp. 7–12, 17, 72; [1989], pp. 68, 202). So the non-realism of CE is of the ontological and by implication of the epistemic kind with respect to both unobservables and modalities; cf. Niinniluoto ([1999], p. 3).

tension, because CE needs observability to be an epistemic notion whereas CE considers modalities to be pragmatic notions (Ladyman [2000] delves into this tension).

The perceived tension, however, is not real. CE is not in trouble. Appearances deceive. The observability of object *X* is *not* a modal concept: it is *not* to be construed as '*the possibility* to observe *X*', but as '*our ability* to observe *X*'. By making this *slightly* revisionary move with respect to the vulgar tongue, as Bacon would say, one can coherently maintain that observability is epistemic and that all modal concepts are not. Van Fraassen ([1980], p. 17, cf. [1985], pp. 252–8):

> The human organism is, from the point of view of physics, a certain kind of measuring apparatus. As such it has certain inherent limitations—which will be described in detail in the final physics and biology. It is these limitations to which the 'able' in 'observable' refers: our limitations *qua* human beings.

Like 'breakable', 'inflammable', 'portable' and 'consumable', 'observable' is an *objective* dispositional property; like 'breakable' and 'portable', but unlike 'inflammable' and 'consumable', 'observable' is *vague*; and unlike 'breakable' and 'inflammable' but like 'portable' and 'consumable', 'observable' is *anthropomorphic* in that some object is observable-*to-us*, just like some object is portable-*by-us* or consumable-*by-us*. This means that observability is a *relation* between concrete objects and what van Fraassen has called the *epistemic community* ($\mathcal{E}$), which consists of all living human beings with healthy eyes and healthy and unclouded minds (cf. van Fraassen [1980], pp. 18–9; [1985], pp. 253–8). What 'healthy eyes' are is a medical problem, and what a 'healthy mind' is is a psychiatric problem; these problems are not philosophical problems: we gladly accept here what the doctors say. The phrase 'unclouded mind' is an umbrella term for being sober, not under the influence of drugs, and what have you. Borderline cases, whose existence would testify for the vagueness of the term 'epistemic community' (not for its meaninglessness), should not be given membership of $\mathcal{E}$; in this fashion we play it safe.

Van Fraassen (in his [1980], p. 16) provides nothing less than a principle formulated in non-modal, extensional language to tell us what is observable (our **bold face**):

> The principle is: *X* is *observable* if there are circumstances which are such that, if *X* is present to us under those circumstances, then we observe *X*.

[4] By 'epistemic' we mean here that the concept is always involved in deciding whether a given proposition of an accepted scientific theory counts as *scientific knowledge*, and by '(purely) pragmatic' when it is not always (never) involved in this. According to CE, the concepts of explanation and of inference-to-the-best-explanation are examples of pragmatic concepts, whereas the concepts of phenomenon, truth and empirical adequacy are epistemic.

> This is not meant as a definition, but only as a **Rough Guide** to the avoidance of fallacies.

Hopefully this sufficient condition for observability is also meant as a necessary one, otherwise we could never decide when something is *unobservable*—van Fraassen talks about unobservables all over the place. Let Obs(X, $\mathcal{E}$) abbreviate 'concrete object X is observable to the naked eye of every $p \in \mathcal{E}$'; let Front(p, X), where $p \in \mathcal{E}$, abbreviate 'p is at rest with respect to X, and is in front of X with his healthy eyes wide open'; and let Sees(p, X) abbreviate 'p sees X veridically'.[5] Then we can abbreviate the Rough Guide as follows:

$$\text{Obs}(X, \mathcal{E}) \longleftrightarrow \forall p \in \mathcal{E} : \text{Front}(p, X) \longrightarrow \text{Sees}(p, X) \qquad (1)$$

We call conditionals like the one to the right of 'iff' (the double arrow) in (1) *indicative observation conditionals*, or *io-conditionals* for brevity (we equate indicative conditionals with material conditionals). Rough Guide (1), however, does not avoid fallacies, as van Fraassen meant it to. On the contrary, it invites a fatal fallacy.

Consider electrons on some planet in some galaxy far far away, or neutrinos in the center of the Sun, which are both places where no member of $\mathcal{E}$ was, is or ever will be present. Consider microbes that live near the bottom of the ocean, an area the size of countries in the deep black sea where no man has ever been and no ray of light has ever entered. In these situations the antecedent Front(p, X) of Rough Guide (1) is False, the io-conditional is therefore True and we must conclude that these electrons, neutrinos and microbes are *observable*.[6] This, surely, is a *reductio ad falsum* of Rough Guide (1).

The Modal Rough Guide. The general problem with Rough Guide (1) is that the io-conditional renders a single object *observable* as long as no one was ever near it. Such objects virtually exhaust all objects in the universe! Monton & van Fraassen ([2003], p. 409) provide, following Ladyman ([2000], p. 184), a way out: 'The natural way to read it is a *counterfactual*.' Call this the

> **Modal Rough Guide.** Concrete object X is *observable* iff there are circumstances which are such that, if X *were* present to us under those circumstances, then we *would* observe X.

[5] By '*p sees X veridically*' (C. D. Broad) we mean that an image of X is evoked on the retina of p's eyes that somehow 'causes', via the optical nerve and the brain, some corresponding mental event of p, frequently called a 'perceptual event'. Such an event happens to p; and p may word this perceptual event in his language, thus resulting in the expression of a 'perceptual proposition'. Then delusions, imagining things and dreams do not fall under Sees(p, x), which is what we want.

[6] We denote True and False with initial capital letters in order to distinguish them from true-in-a-model and false-in-a-model respectively (concepts which are going to play a major rôle further on in this paper). We mean Truth in the plain sense of correspondence with an actual fact, or in some deflationary sense, or whatever other philosophical account of Truth as long as it does not *overtly* prejudge on the realism issue with respect to unobservables and modalities.

With the standard abbreviation ($\Box\!\!\rightarrow$) for a subjunctive would-conditional,[7] we can abbreviate the Modal Rough Guide as follows:

$$\mathrm{Obs}(X,\mathcal{E}) \longleftrightarrow \forall p \in \mathcal{E} : \ \mathrm{Front}(p,X) \Box\!\!\rightarrow \mathrm{Sees}(p,X) \tag{2}$$

We call conditionals like the one to the right of 'iff' in (2) *subjunctive observation conditionals*, or *so-conditionals* for brevity. We keep calling them 'so' if the antecedent or the consequent, or both, have a negation-sign in front of them. And parenthetically *mutatis mutandis* for io-conditionals (1).

Since a so-conditional is a *modal* proposition, Ladyman's tension between the epistemic concept of observability and the pragmatic modal concepts now seems to have been restored in CE, because Modal Rough Guide (2) explicitly states their logical connexion. Is CE in trouble after all?

The restored tension is, again, not real, or so Monton & van Fraassen ([2003], pp. 410–1) claim in their response to Ladyman. CE is not in trouble. They essentially admit that not *all* subjunctive conditionals are *flatus vocis* or pragmatic. For instance, $\varphi \Box\!\!\rightarrow \varphi$ is a perfectly acceptable logically True subjunctive would-conditional, and Modal Rough Guide (2) is a perfectly acceptable epistemic subjunctive conditional. Then they go on to *deny* that 'inflationary metaphysics', e.g. belief in the existence of a bizarre infinitude of other possible worlds treated on an equal ontological footing with the actual world, called *Modal Realism*, is needed to make sense of Modal Rough Guide (2) in particular and of subjunctive conditionals in general. They claim that, on closer inspection, subjunctive conditionals do not require Truth-conditions that transcend what in principle we can publicly verify or falsify, or that rely on the inflationary metaphysics of Modal Realism (cf. Section 7[8]). Monton and van Fraassen write ([2003], p. 410, our italics):

> The sense in which counterfactuals are here held *not* to have an *objective truth-value* is that they are *in general context-dependent*. The context in which they are asserted is one in which the speaker is holding something fixed, which together with the antecedent implies the consequent. What is held fixed *tends to include a good deal of unformulated general opinion*, but also *features specific to the case*. The conditional has a truth-value, relative to such a context; but that value will vary with context. When it is true it is because a *certain conditional* in this contextual background is *logically true*. (3)

[7] A *counterfactual* is a subjunctive conditional with a False antecedent, which is usually the case when a counterfactual is asserted.

[8] Is it necessary to be a Modal Realist in order to believe in objective modalities in nature? The working hypothesis in this paper and in van Fraassen's writings on modality is an answer in the affirmative. Let us conjecture, for those who answer in the negative, that van Fraassen will classify any account of objective modality in nature as 'inflationary metaphysics' because it will transcend the phenomena in the actual world, far beyond what can in principle be tested. With this conjecture in position, we move on.

This is in perfect harmony with van Fraassen's early construals of subjunctive conditionals more than twenty years ago ([1975]; [1981], p. 194). So if one takes objectivity to imply context-*independence* (Obj), as Monton & van Fraassen tacitly do (but we reject), then subjunctive conditionals do not have *objective* truth-conditions. But if one considers the *objectivity* of the proposition to be safe as long as the Truth-conditions can *in principle* be publicly verified or falsified in the actual world without recognisably 'subjective elements' entering the process, then subjunctive conditionals remain as *objective* as their indicative siblings. This seems to be the case in quotation (3). Therefore the objectivity of $\Box\!\!\rightarrow$ is not lost, in contrast to what Monton & van Fraassen claim on the basis of their dubious (Obj). Elsewhere van Fraassen contrasted objectivity to being immersed in the world-picture of a particular scientific theory, to working in its virtual reality and expressing oneself using its language ([1980], p. 82). If this, too, qualifies as 'being in a context' and hence as an instantiation of context-dependence, then there is, also given the fact that, as van Fraassen puts it ([1980], p. 14), 'all our language is thoroughly theory-infected,' no context-independence to be found in science. Then by (Obj) there is no objectivity in science either. But if even *science*—the stronghold of objectivity *par excellence* in our culture—lacks objectivity according to (Obj), then this consequence plausibly is a nail in the coffin of (Obj). So much for objectivity—nothing essential will depend on this difference in meaning ascribed to the word 'objective'.

Let us now try to state more precisely what Monton & van Fraassen are saying in quotation (3) about how to construe $\Box\!\!\rightarrow$. Their construal is essentially a Quinean one. Let C be some context. Let Γ_C be the 'relevant part of the Propositional content of C', thus including 'a good deal of unformulated general opinion' and 'features specific to the case' (3).[9] Let φ, χ be two propositions. What is proposed in quotation (3) seems to be the following:

$$\mathrm{Tr}(\varphi \Box\!\!\rightarrow \chi) \text{ in context } C \quad \text{iff } (\Gamma_C \wedge \varphi) \vdash \chi \tag{4}$$

where $\mathrm{Tr}(\varphi)$ abbreviates 'it is True that φ'. The 'certain conditional' which is 'logically true' in quotation (3), then, must be the following theorem of logic (by virtue of the Tarski-Herbrand Deduction Theorem):

$$(\Gamma_C \wedge \varphi) \longrightarrow \chi \tag{5}$$

A logically weaker construal of 'logically true' is by means of semantic implication; rather than (5) we then have:

$$(\Gamma_C \wedge \varphi) \Longrightarrow \chi \tag{6}$$

which is implied by (5) but not conversely, unless the logic we use is complete.

9 The notion of the 'propositional content of a context' is something *we* bring in here, by conceptual necessity, because only propositions can 'imply' anything, which is what Monton & van Fraassen are saying (3). That this is the way to go is also clear from van Fraassen ([1975] and [1981], p. 194).

Let us apply construal (4) to the Modal Rough Guide (2). When we use 'context' and 'circumstance' interchangeably, we obtain the

> **Construed Modal Rough Guide.** Concrete object X is *observable* iff there are contexts which are such that the relevant part of their propositional content and the proposition that X is in front of us together imply that we see X.

In terms of our abbreviations and of construal (4) of subjunctive would-conditionals, the Modal Rough Guide is this:

$$\mathrm{Obs}(X, \mathcal{E}) \longleftrightarrow \exists C,\ \forall p \in \mathcal{E} : (\Gamma_C \wedge \mathrm{Front}(p, X)) \longrightarrow \mathrm{Sees}(p, X) \qquad (7)$$

The conclusion is that the modal character of the so-conditional belongs to its surface grammar; what Monton & van Fraassen are saying here is that when we analyse the Modal Rough Guide (2) *properly*, we see that down under it is a non-modal statement (7) posing as a modal one (4).

Psillos' Problem. Modal Rough Guide (7) is, however, circular, in that it is like a lamp that only works when another lamp has already been switched on so that it has become otiose. We explain.

Consider the following two so-conditionals.

> (A) If Bas *were* 10 km from Callisto in his flying saucer and *were* to look through the window, then he *would see* this moon of Jupiter.
> (B) If James *were* to stand in a typical Jurassic landscape right in front of a living Tyrannosaurus in broad daylight with his eyes wide open, then he *would see* this enormous reptile. (8)

Only if so-conditionals (8) are True does criterion (7) license one to say that Callisto and a living Tyrannosaurus are observable. Well, in the Section called 'The Vagaries of Observability' of his ([1999]) (pp. 193–200), Psillos argues (to stick to our examples) that to imagine (A) Bas looking at Callisto from his flying saucer and then seeing this moon of Jupiter means to enter a *science-fiction context*. We can add that putting (B) James in some Jurassic landscape right in front of a living Tyrannosaurus also means to enter a *science-fiction context*—a journey with the Time Traveller, as in Wells ([1895]), or some genetic doctoring, as in Spielberg ([1993]). If science-fiction contexts are permitted, Psillos continues, we can consider the following science-fiction context: Bas is put in a yellow submarine, is decreased in size several orders of magnitude by means of some miraculous technological device, and the tiny sub with content is injected into the blood stream of a nasty gentleman, where Bas experiences all kinds of crazy adventures; then blood cells, microbes and in fact the entire microscopic world becomes *observable*.[10] In some other

[10] According to our best physical theories about matter, scaling material objects is not possible, because the 'size' of atoms (e.g. the Bohr-radius) is determined by constants of nature and intrinsic properties like mass and charge, none of which we can change (cf. Tomonaga [1962], p. 105). We gloss over this.

science-fiction context, blood cells are increased to the size of pancakes by some other miraculous reverse technological device, which makes them, and all other microscopic objects treated similarly, *observable-by-us* (cf. Psillos [1999], pp. 190–1). So by being sufficiently imaginative in telling science-fiction stories, we can make every single object observable. It is all a matter of imagining some context. Calling an object unobservable is a lack of imagination.

This is, surely, a *reductio ad falsum* of Modal Rough Guide (2).

So, clearly, if we want to avoid Psillos' conclusion that the observability-distinction cannot be drawn coherently because we can make every object observable, not every context imagined is permitted to occur in the class of contexts over which $\exists$ in (7) ranges: a context with Bas as an interplanetary traveller going beyond where any man has gone before, and a context with James in a time machine going to the Jurassic Age, where no man has gone before either, are both *permitted*; but a context with some 'microscopised' human being (henceforth *microman*), and a context with pancake-sized blood cells must be *forbidden*. Where, then, to draw the line? What *is* the range of $\exists$ in (7)? The domain of quantification seems up for grabs. Call this *Psillos' Problem*.[11] If the current rescue attempt of Modal Rough Guide (2) is to succeed, a solution of Psillos' Problem is mandatory.

The line cannot be drawn between science-fiction contexts and science-fact contexts because, as we have just seen, some science-fiction contexts definitely are permitted (8). Nor can the line be drawn between contexts which involve actual objects only and those which involve also possible objects that are fictional (hence non-actual), because the concept of observability (which we are in the process of grounding by means of subjunctive would-conditionals) and the concept of existence are, according to van Fraassen ([1980], pp. 18, 197), *logically independent* (neither implies the other):

> A flying horse is observable—that is why we are so sure there aren't any . . .
> The ride of the headless horseman is an observable event, but not an actual one. (9)

Hence these are not successful rescue attempts of Modal Rough Guide (2). We try another one.

A solution of Psillos' Problem seems to be emerging when we point out that not everything can be permitted to be done to members of $\mathcal{E}$. Some things *make them lose their membership in* $\mathcal{E}$. For instance, making human beings a few

[11] Let us mention here that various distinct arguments have been propounded to the same effect as how Psillos sees his argument (by M. Friedman, A. Kukla, R. Creath, A. Musgrave and others), namely as establishing that the observability-distinction cannot be drawn coherently within CE; we have handled these arguments elsewhere, in a satellite paper to the present one, Muller ([2004]).

orders of magnitude *smaller* is forbidden, as is surgically implanting X-ray microscopes in their eye-sockets, and as is removing their eyes altogether. But moving human beings about in space and time is permitted, as is presumably a visit to the hair-dresser, losing a finger, or two legs, or perhaps even becoming colour-blind. Some physiological changes are definitely permitted, whereas others are definitely forbidden. (We notice parenthetically that space and time travel, just like the more drastic changes we suggested above, result in physiological changes, for instance in the brain, where new experiences will be stored which can be remembered, told, written down or discussed at a later date. So we cannot say that a context is permitted iff no physiological changes of $p \in \mathcal{E}$ are involved.) Psillos has made that much abundantly clear. Why should many physiological changes be permitted, in spite of the fact that some of them seem quite drastic? The answer is, of course, that these changes seem irrelevant for matters concerning observability. Losing your finger or your legs does not affect your eye-sight, but shrinking you a few orders of magnitude or transplanting X-ray microscopes in your eye-sockets supposedly does affect it. When we remind ourselves that our ability to observe determines the subclass of observables of the class of all concrete objects, it seems that the following criterion for allowing a context is the right one: a context is *permitted* iff the physiological changes of members of ε occurring in this context (if there are such changes at all) leave the class of observables invariant; and a context is *forbidden* iff it is not permitted ($\otimes$). Psillos' Problem solved at last?

What a pity we happen to be in the process of explaining a guide for deciding what an observable is! Only if we can already decide what an observable is can we draw the required distinction between permitted and forbidden contexts by means of criterion ($\otimes$). In this fashion Modal Rough Guide (2) is only useful if it has no use anymore. In other words, the current rescue attempt of the Modal Rough Guide faces a *reductio ad circulum*.

How to break this circle? How to draw the line between forbidden and permitted contexts without surreptitiously relying on the concept of observability? This is Psillos' Problem all over again.

The Context Problem. Further, we also submit that van Fraassen & Monton's description of 'a context' is too vague and too general for the philosophical task it is required to perform. This is, ultimately, nothing less than grounding the epistemic policy of CE.[12] The problem of how to make 'context' here more precise and rigorous than 'a good deal of unformulated general opinion' and 'features specific to the case' we call the *Context Problem*.

[12] Uttering '*Context!*' seems a *deus ex machina* of the past fifty years of philosophy. Are you in trouble? Contextualise! Without further explication and clarification, such utterances are more like performing an act of philosophical magic than propounding a philosophical argument. Philosophy is not sorcery.

Musgrave's Problem. Musgrave's Problem is the problem of how CE can acquire, for every concrete object X, the belief (that it is True) that X is observable or the belief (that it is True) that X is unobservable. CE needs to answer this question in order to have objective grounds for demarcating the objective scientific knowledge that every accepted scientific theory includes from what is its pragmatic toolkit (cf. Muller [2004]). We have called this problem 'Musgrave's Problem' because it arose in the context of a piercing argument due to A. Musgrave ([1985], p. 208) to the effect that CE cannot solve this problem. Succinctly, the argument says that if we *accept* a theory and by implication its unobservable posits, we cannot come to believe that is True that the posits (whether they exist or not) *are unobservable*, due to the the epistemic policy of CE. Van Fraassen ([1985], p. 256) responded to Musgrave, but this response is not enough to solve Musgrave's Problem (cf. Muller [2004], pp. 89–90). For the present purposes it suffices to know that elsewhere we left Musgrave's problem unsolved but promised to solve it (Muller [2004], p. 96]). Since Musgrave's Problem has everything to do with observability, the present paper is the appropriate place to fulfil that promise.

Modality. In the dialectic above we have seen how observability and modality have become intertwined, but observability remained the concept in the limelight; now we draw modality into the limelight. We claim, with Ladyman ([2000]), that any tenable view of science must provide a general and comprehensive account of modality in science. To emphasise, this claim is not a conclusion drawn from the dialectic we have reviewed above, but if 'the central motivation' for CE is 'how to make sense of science best', as Monton & van Fraassen put it ([2003], p. 421), then CE must make sense of modal language in science and CE must do so without Modal Realism, and within the semantic view on scientific theories. Although Monton & van Fraassen ([2003], pp. 406, 420) have submitted that CE and Modal Realism are *logically compatible* because CE is a view of science and the other a view of modality, they have also admitted that adopting Modal Realism would scandalise the pivotal motivation for adopting CE, namely to have a view of science 'without inflationary metaphysics'. Indeed, CE and Modal Realism jointly provide an incoherent mixture.

Aims of this paper. The major aim of this paper is to provide a precise account of observability that solves, or dissolves, Psillos' Problem, the Context Problem and Musgrave's Problem, and which, of course, vindicates our standard judgments of observability. The other major aim is to provide a rigorous account of modal language in science, notably including subjunctive conditionals, without relying on Modal Realism, without even mentioning fictional worlds, and staying within the confines of the semantic view on scientific theories. To show how the two major aims are related is a minor aim of this paper; it will be reached as soon as the two main aims are reached.

Preview. We begin by hunting down a scientifically informed guide to observability, formulated in completely extensional language; this hunt will be successful, or so we argue, yet with a qualification (Section 3). Then we propose a precise and useful definition of observability that fits more naturally in the dialectic we have been reviewing above, which is formulated in extensional language and does not even contain a single conditional (Section 4). We show how the definition solves the Context Problem and Psillos' Problem (Section 5), and Musgrave's Problem (Section 6). Then we sketch a succinct and precise non-realist account of the notions of possibility, contingency and necessity and of subjunctive conditionals in the framework of scientific theories and models (Section 7), which we rehearse first of all.

2 The semantic view and the wave theory of light

Besides (a,b) summarising what *the semantic view* on scientific theories is, we (c,d) also introduce a few definitions for future use (cf. van Fraassen [1972], [1980], pp. 64–9, [1989], pp. 217–32; Muller [1998], pp. 253–307); then (e) we direct our attention to the wave theory of light.

(a) A *scientific theory* **T** is a set of models. A *model* is a linguistic-mathematical entity, an ordered pentuple

$$\mathcal{M} \equiv \langle \mathfrak{S}, \mathcal{S}, R, v, \Phi \rangle \tag{10}$$

of a *set-theoretical structure* $\mathfrak{S}$, an optional set of states $\mathcal{S}$, a concomitantly optional binary relation on the states, $R \subseteq \mathcal{S} \times \mathcal{S}$, an admissible valuation $v : \mathcal{S} \rightarrow \wp\Phi$, and a set of propositions Φ expressible in what is standardly considered to be 'the language of the theory **T**', denoted by $\mathcal{L}_{\mathbf{T}}$, that we are trying to characterise rigorously. Items $\mathfrak{S}$, $\mathcal{S}$, R are all captured by some predicate in the language of axiomatic set-theory.[13] In mathematically well-developed branches of science, notably physics, the set of states S usually is part and parcel of the structure $\mathfrak{S}$ and therefore already specified by working physicists (and if not, it is in general not difficult to do so). In mathematically underdeveloped branches of science, notably the social and the life sciences, some fancy rigorous footwork is needed to civilise the models constructed and used by the scientists working in these branches in order to allow them to occupy a chamber in the palace of the semantic view.

We next (b) add some explanatory remarks about the semantic view; then we define a few concepts that CE employs to make sense of scientific theories

[13] ZC say, which is Zermelo's axiomatisation of 1908 cleaned up and enriched with the axioms of Regularity and Choice. We abbreviate its domain of discourse by **V**. The set of all sets having an ordinal rank smaller than $\omega + \omega$, denoted by $\mathbf{V}_{\omega+\omega}$, contains all the mathematics, when set-theoretically reduced, that science has ever used, is using and ever will use, as a moment's reflection will reveal.

and their relations to the world by (c) concentrating on the structural features of $\mathcal{M}$ (10), which are $\mathfrak{S}$, $\mathcal{S}$ and R, and by (d) concentrating on its linguistic features, which are Φ, v and the truth-predicates that v will generate.

(b) The relation R is supposed to accommodate, whenever appropriate, the idea that if the modelled object, system, organism, subject, event, process or whatever is in a particular state (at a particular time), say $s \in \mathcal{S}$, another state, $r \in \mathcal{S}$ say, is accessible from that state. In that case sRr holds. The propositional content of language $\mathcal{L}_{\mathrm{T}}$, denoted by $[\mathcal{L}_{\mathrm{T}}]$, is the propositional content Φ of all models $\mathcal{M} \in \mathbf{T}$ lumped together. For the sake of convenience we sometimes also call $\mathfrak{S}$ a model in $\mathbf{T}$, and we write things like $\Phi \in \mathbf{T}, \mathfrak{S} \in \mathbf{T}, \Phi \in \mathcal{M}$, etc. In Model Theory, a model makes a sentence true or false by means of the Tarskian satisfaction-relation ($\models$). Here, in the semantic view on scientific theories, a state $s \in \mathcal{S}$ of the model $\mathcal{M}$ makes propositions of Φ true and others false—and perhaps still others indeterminate if *tertium datur*, but for the sake of simplicity we assume semantic bivalence: φ is false iff $\neg\varphi$ is true. Given the valuation v, we then have that *state* $s \in \mathcal{S}$ *makes* proposition $\varphi \in \Phi$ *true* in model $\mathcal{M}$, denoted by $\mathrm{tr}(\mathcal{M}, s, \varphi)$, iff φ belongs to the value of s under v; we can then also define that the *model* $\mathcal{M}$ makes φ *true*, denoted by $\mathrm{tr}(\mathcal{M}, \varphi)$, iff every state in the model makes φ true:

$$\begin{aligned} \mathrm{tr}(\mathcal{M}, s, \varphi) &\longleftrightarrow \varphi \in v(s) \\ \mathrm{tr}(\mathcal{M}, \varphi) &\longleftrightarrow \forall s \in \mathcal{S} : \mathrm{tr}(s, \varphi) \end{aligned} \tag{11}$$

If there is not a set $\mathcal{S}$ of states present in the model $\mathcal{M}$ (10), or if it is too artificial to bring one in, one begins with $\mathrm{tr}(\mathcal{M}, \varphi)$ *à la* Tarski rather than with $\mathrm{tr}(\mathcal{M}, s, \varphi)$. (State-independent true statements in a model equipped with a set of states $\mathcal{S}$, such as purely mathematical statements made true *à la* Tarski, can be required to be in $v(s)$, for every $s \in \mathcal{S}$, by way of an additional admissability requirement on v.) The presence of $\mathcal{S}$ and R will accommodate the use of modal language within a single model (cf. Section 7).

(c) Every scientific theory $\mathbf{T}$ is supposed to be about some set of all phenomena that have occurred, are occurring or will occur in the universe. From every phenomenon we can 'extract', by means of doing observations and performing experiments, *data structures* (usually consisting of numbers). They also live in the set $\mathbf{V}_{\omega+\omega}$ (cf. footnote 13); we call the set of all *these* data structures the *domain* of $\mathbf{T}$ and denote it by Dom($\mathbf{T}$); then Dom($\mathbf{T}$) $\in \mathbf{V}_{\omega+\omega}$. To say that model $\mathcal{M}$ *saves a phenomenon* is to say that $\mathcal{M}$ *embeds* every relevant data structure $\mathcal{D} \in$ Dom($\mathbf{T}$) extracted from that phenomenon; this means that $\mathfrak{S}$ of $\mathcal{M}$ (10) has a substructure, called the *empirical substructure* of $\mathcal{M}$, to which that data structure is homomorphic or even isomorphic. Every model in $\mathbf{T}$ that embeds some data structure in Dom($\mathbf{T}$) we call an *actual model*; those models are about the actual world. One can lump all actual models together in one gigantic model called *the actual model*, denoted by $\mathcal{M}_{@}$, provided we extend definition (10) to any polytuple consisting solely of pentuples of the form of $\mathcal{M}$ (10). When we also build a single data structure out of all data structures in Dom(**T**), and denote this most encompassing data structure relevant for **T** by $\mathcal{D}_@$, we can express the *empirical adequacy* of **T** as $\mathcal{D}_@$ being embeddable in $\mathcal{M}_@$:[14]

$$\text{EmpAd}(\mathbf{T}) \longleftrightarrow \text{Emb}(\mathcal{D}_@, \mathcal{M}_@) \tag{12}$$

(d) We emphasise that Truth, truth-in-a-model and truth-in-a-model-by-a-state, $\text{Tr}(\varphi)$, $\text{tr}(\mathcal{M}, \varphi)$ and $\text{tr}(\mathcal{M}, s, \varphi)$ respectively, are conceptually distinct. Let us point out that we also can consider the theory as a truth-maker: proposition φ, expressible in $\mathcal{L}_T$, is a **T**-*theoretical truth* iff every model in **T** makes φ true:

$$\text{tr}(\varphi,\ \mathbf{T}) \longleftrightarrow \forall \mathcal{M} \in \mathbf{T}:\ \ \text{tr}(\mathcal{M}, \varphi) \tag{13}$$

In the light of definition (12), let us further call φ a **T**-*actual truth*, denoted by $\text{tr}_@(\varphi,\ \mathbf{T})$, iff some state in the actual model of **T** makes it true:

$$\text{tr}_@(\varphi, \mathbf{T}) \longleftrightarrow \exists s \in \mathcal{S}_@:\ \ \text{tr}(\mathcal{M}_@, s, \varphi) \tag{14}$$

where $\mathcal{S}_@$ is the union-set of all sets of states in $\mathcal{M}_@$. Hence **T**-theoretical truths (13) and **T**-actual truths (14) are in general logically independent. But if **T** is empirically adequate (12), all **T**-theoretical truths are also **T**-actual truths.

When it comes to scientific propositions generally, van Fraassen ([1980], p. 38) has declared about CE that 'it assumes scientific statements to have truth-conditions entirely independent of human activity or knowledge.' And van Fraassen ([1997], §4.4) says about the statement 'Electrons always have a precise position' (∗): 'If (∗) is a statement in our language in use, then whether (∗) is true or not simply depends on what electrons are like.'[15] Hence van Fraassen subscribes to what is called *semantic realism*: the Truth-conditions of propositions supervene only on the world; they are independent of our existence, our activities (epistemic or otherwise), desires, hopes and beliefs. Since van Fraassen also takes scientific statements literally, we consider Tarski's T-schema for propositions to be the minimal expression of semantic realism, because it says that *any proposition is its own Truth-condition* (cf. van Fraassen [2003], p. 482):

$$\text{Tr}(\varphi)\ \text{iff}\ \varphi \tag{15}$$

The following schemas seem appropriate. For the Truth of a scientific theory, the following schema: any **T**-actual-true proposition (14) is True, and *vice versa*. So **T** is True, denoted by Tr(**T**), iff the following schema holds: for any $\varphi \in [\mathcal{L}_\text{T}]$,

$$\text{tr}_@(\varphi, \mathbf{T}) \longleftrightarrow \text{Tr}(\varphi) \tag{16}$$

[14] Van Fraassen explains the empirical adequacy of a theory ([1980], p. 12): 'A little more precisely: such a theory has at least one model that fits all the phenomena inside. I must emphasize that this refers to *all* phenomena.' Cf. Chapter 3 of his ([1980]). Simpler and more straightforward would be to define the empirical adequacy of **T** as there being some model $\mathcal{M} \in \text{T}$ for every relevant data structure $\mathcal{D}$ such that $\mathcal{M}$ embeds $\mathcal{D}$.

[15] Cf. van Fraassen ([1980], pp. 90, 197; [1989], pp. 177, 181, 192, 218; [2003]).

Call any proposition φ that is only about existing observable objects or images (*e.g.* reflections, rainbows, holograms, projected pictures), or both, *empirical*, denoted by Emp(φ). Then **T** is empirically adequate (12) iff the same schema as (16) holds but restricted to empirical propositions:[16]

$$\mathrm{Emp}(\varphi)\longrightarrow\big(\mathrm{tr}_{@}(\varphi,\mathbf{T})\leftrightarrow\mathrm{Tr}(\varphi)\big) \qquad (17)$$

(e) We now consider the particular generally-accepted scientific theory which describes how light behaves at the level relevant for questions of observability: the wave theory of light. This is a sub-theory of Faraday-Maxwell electro-dynamics and in turn has ray optics as a sub-theory. Rather than to consider *all* models in this theory, we consider the subset **L** of models $\mathcal{M}$ having structures $\mathcal{L}$ of the following two types:

$$\langle\mathbb{R}^4, S, \mathrm{e}_p, X, \vec{E}\rangle \text{ and } \langle\mathbb{R}^4, S, \mathrm{e}_p, \vec{E}\rangle \qquad (18)$$

Here $\mathbb{R}^4$ represents (is a Cartesian co-ordinate frame on) Minkowski space-time; S is a light-source (a concrete object producing visible light); e_p are the eyes of member p of our epistemic community ($\mathcal{E}$) modelled by a small convex lens (having relevant properties of the lens of the human eye, such as its focal distance) and a little screen a few centimeters behind it (the retina) having a certain resolution-power and sensitivity-threshold (matching these of the human eye); X is a concrete object; and $\vec{E}:\mathbb{R}^4\rightarrow\mathbb{R}^3$ is the electric field of the light emitted by S, which is the electric component of the solution of Maxwell's equations. The first type of model in **L** (18) describes how light emitted by S is reflected by X into e_p; the second type describes the situation in which the object itself emits light ($S=X$, so to speak), some of which falls into e_p.

3 A scientific guide and a scientific criterion

In the dialectic reviewed in the Introduction, we saw Monton & van Fraassen responding to the exposed flaw of the conditional Rough Guide (1) by saying that it should be understood as a *different* conditional (as a *subjunctive* one rather than as an *indicative* one). This led to the problem how to define objective, actual Truth-conditions of subjunctive conditionals; the solution they provided gave rise to Psillos' Problem and to the Context Problem. Another response to the exposed flaw of the original Rough Guide (1) is to formulate a fresh guide that involves *no* conditional propositions at all. In the present section we make an attempt to do precisely this. We argue that although this attempt certainly fares better than the Rough Guides we have seen so far, it is difficult to apply.

[16] Cf. van Fraassen ([1980], p. 12): 'a theory is empirically adequate exactly if what it says about the observable things and events in this world is true—exactly if it "saves the phenomena".'

To direct the mind, let us first see how we can characterise another anthropomorphic and vague property of a concrete object in non-conditional and objective terms: 'passability' of a door-frame, meaning our ability to pass the door-frame when the door is open. Passability means passability-*for-us*. An objective, rigorous, non-anthropomorphic criterion that involves neither modal language nor conditional propositions is the following one: a door-frame is *passable* iff it is about at least 1 metre wide and 2 metres high. Of course the choice of 1 and 2 m is *anthropomorphically motivated*, no question about it, but the criterion itself only states a particular minimum width and height and does not mention human beings or their properties, in contradistinction to the Rough Guides to observability we have seen so far. We have 'taken ourselves out of the equation', so to speak. Such taking-out we now attempt to do for observability. For this we turn to science, in full concordance with van Fraassen's assertion ([1980], p. 57) that observability is a subject for scientific research and not for philosophical analysis.

We turn to Graham ([1965]), which is a collection of scientific research and review papers about the visibility of all kinds of concrete objects and the conditions under which they are seen by test-persons.[17] The following scientifically informed guide to observability emerges:

$$\textbf{Scientific Guide}.\quad \mathrm{Obs}(X,\mathcal{E}) \longleftrightarrow \mathrm{Macro}(X) \wedge \mathrm{Light}(X,\mathcal{E}) \qquad (19)$$

where Macro(X) abbreviates 'X is macroscopic', and Light(X, $\mathcal{E}$) 'our eyes register the light that is emitted from or reflected by X, and not only transmitted by X, under natural conditions'. We break the elucidation of this Guide into six parts: (i) the determination of Macro(X); (ii) the nature of light; (iii) the sensitivity of our eyes (as the members of $\mathcal{E}$); (iv) the emission or reflection of light by object X; (v) the phrase 'natural conditions'. Then (vi) we show how to eliminate the conjunct Macro(X) from the Scientific Guide (19) and finally arrive at a scientific criterion for observability.

(i) To be able to see an object, it must be larger than a certain size. Electrons and E-coli bacteria are unobservable because they are too small to be seen with the naked eye. This much is obvious. So we take 'macroscopic' to stand for 'having a minimal size'. What is this minimal size? Test persons can just resolve a grating of equidistant vertical black and white lines in front of them when the width of the lines subtends about 1 minute of arc ($1'$). But to see whether a thick black vertical line is cut and the top part is slightly horizontally shifted (a so-called 'vernier displacement'), the shift can be as small as 3 seconds of arc—a black spot of about 0.01 mm, which is smaller than a point

[17] There is a case to be made to extend the concept of observability to other sense organs besides the eyes. We do not make it here and thus equate observability with visibility—the eye outranks the other senses *qua* importance by far.

in printed text, at a distance of about 1 m subtends such an angle (cf. Graham [1965], pp. 325–6). In these cases bright illumination is assumed, such as broad daylight. These and similar photometric data suggest taking the following for 'minimal size':

> **Criterion**. Macro(X) iff at about 10 cm the size of X subtends a spatial angle of about $1'$. (20)

We have chosen 10 cm in criterion (20) because this is roughly the distance below which healthy eyes have difficulty in focusing. At a distance of 10 cm we can easily see a point in printed text, but not at 10 km. Of course, 9.97 cm would also do, as would any distance a bit larger than 10 cm, but 0.01 cm will not do, because if you press a sheet of paper against your cornea, you will not see anything. The twice occurring phrase 'about' in criterion (20) locates two sources of vagueness in the Scientific Guide (19).

(ii) Physics currently has two characterisations of light in the offing. The first characterisation comes from the wave theory of light **L** (18). According to Faraday-Maxwell electro-dynamics, an *electro-magnetic field* $\vec{E}, \vec{B} : \mathbb{R}^4 \rightarrow \mathbb{R}^3$ is a solution of Maxwell's equations, and *electro-magnetic radiation* is a periodic electro-magnetic field. All relevant concepts can be defined in terms of space, time and what occurs in Maxwell's equations, which is the electro-magnetic field and two constants (the electric and magnetic permittivity of the vacuum, denoted by ϵ_0 and μ_0 respectively). The field's speed of propagation is demonstrably $(\epsilon_0\mu_0)^{-1/2}$, denoted by c, known as 'the speed of light' (about 300,000 km per second). The *period* of the periodic electro-magnetic field $\vec{E}_\nu(r, t), \vec{B}_\nu(r, t)$, denoted by T, is the time the field takes to complete one cycle at a particular point in space, say r_0. By definition, the *frequency* ν is the inverse of the period ($\nu \equiv 1/T$), and the *wavelength* λ is the distance travelled by the field during one period ($\lambda \equiv cT$), so that $c = \nu\lambda$. In order to obtain the total strength $|\vec{E}(r_0, t_0)|$ of the field at space-time point $(r_0, t_0) \in \mathbb{R}^4$, one must first integrate $\vec{E}_\nu(r_0, t_0)$ over all frequencies. The *intensity* I of the radiation (energy per unit area per unit of time) is proportional to the square of the field-strength: $I \propto |\vec{E} + \vec{B}|^2$, which can be approximated by $|\vec{E}|^2$ because in general $|\vec{E}| = c|\vec{B}|$, so that the contribution of $\vec{B}$ to the intensity I is about 16 orders of magnitude smaller than the contribution of $\vec{E}$.

The wave theory of light is silent about how light is produced; for that we must turn to quantum-theory. Which brings us to the second characterisation of light. According to quantum-theory, light is a stream of indivisible energy-packets called *photons*, which have both primitive particle-like and primitive wave-like properties, notably a linear momentum ($p_\lambda = h/\lambda$, where h is Planck's constant) and a wavelength and a frequency, respectively, but *is* neither a particle nor a wave—exactly like all elementary 'particles' of matter. Unlike particles of matter, photons always move with the speed of light and have a constant energy $E_\nu = h\nu = p_\lambda c$. The total intensity I of the light is now obtained by integrating the energy-density $\varepsilon_\nu(r)$ of light over all frequencies, which is proportional to the total number $N_\nu \in \mathbb{N}$ of photons of energy $E_\nu = h\nu$ in the spatial volume V where the photons are present: $N_\nu = \int_V \varepsilon_\nu(r) d^3 r$ and $I = \int_{\mathbb{R}} N_\nu d\nu$.[18]

Although physics currently has two respectable views of light in the offing, which understand the measurable physical magnitudes of light (wavelength λ, frequency ν and intensity I) differently, they relate them to what we see in the same way: *light* is electro-magnetic radiation or a stream of photons having a wavelength between, roughly (another source of vagueness), 400 and 800 nanometres (1 nm $= 10^{-9}$ m), which we call the *visible spectrum*. Wavelengths (and thus frequencies) are correlated to the colours we see, and intensities to the brightness of the light we see. By definition we take *visible light* to be light having an intensity that lies above the 'sensitivity-threshold' of the natural light detector above the noses of the members of $\mathcal{E}$, the human eye.[19]

(iii) The sensitivity-threshold of the eye is a complicated story. It depends on whether we talk about the rods or the cones in the retina, on whether there is photopic or scotopic illumination, on the wavelength of the light, on how long we are allowed to look, on the history of the eye just before we look, and on whether the object is at rest or in motion with respect to the eye. For example, when a person is situated in a dark room for a while, he can register a flash of yellow light (wavelength $\lambda \approx 510$ nm) of about 100 photons, lasting 1 ms and subtending a spatial angle of $1'$ (cf. Graham [1965], p. 154). Longer exposures make the eye less sensitive, up to a factor of 100. For red light ($\lambda \approx 700$ nm), the sensitivity drops by four orders of magnitude in comparison to yellow light; for dark orange ($\lambda \approx 650$ nm), the sensitivity of rods and cones coincides, but for $\lambda \lesssim 500$ nm the rods are about three orders of magnitude more sensitive than the cones (cf. Graham [1965], pp. 158, 72). Hence, to be on the safe side, we can choose for the *sensitivity-threshold* the wavelength-dependent curve $s : \lambda \mapsto s(\lambda)$ of the cones, as depicted in Figure 4.6 in Graham ([1965], p. 72), multiplied by a

18 Everyone knows by now that according to quantum mechanics particles cannot have both a value for their linear momentum (and therefore their velocity) and for their position in the same dimension at the same time. Photons do not form an exception. Well then, if their speed always has value c, do they consequently never have a position in space? Is light always nowhere? If at time $t_0 \in \mathbb{R}$ a photon γ is emitted by a tungsten atom in a light bulb, which is definitely located around some point in space, $r_0 \in \mathbb{R}^3$ say, then what is the status of equation $r_\gamma(t) = r_0 + ct$, which we usually take as describing the world-line of photon γ, forming a light-cone? Etc. Actually everything should be re-phrased in terms of probabilities, the proper way to talk about values of physical magnitudes according to quantum physics. This requires the introduction of a 'position-operator of the photon', a foundational subject with a tortuous history about which still no general agreement has been reached. (Food for philosophers of physics.) We permit ourselves to gloss over this subject entirely.

19 In another, more literal sense, light is *invisible*, as the well-known experiment with the laser beam and the vacuum glass-bell demonstrates. We mean 'visible' in the sense defined in the sentence to which this footnote is appended.

factor of 100 because we want to be sure to see concrete *objects* over some period of time (for at least one second, say), not merely register tiny flashes of 1 ms in the dark of night.

(iv) Whenever green light falls on a tomato, the molecules in (the outer layers) of the tomato bounce back photons of about 700 nm (red) and absorb the rest. Since there are no photons of about 700 nm in green light, all light is absorbed and the tomato appears black. When sunlight falls on the tomato, photons of 700 nm are present; only they are reflected and consequently the tomato appears red. In general this is all determined by the kinds of molecules that constitute the object X and the way the molecules bind each other. Each bound molecule is quantum-mechanically characterised by a Hamiltonian H acting in $\mathcal{H}$, the operator corresponding to the physical magnitude energy, where $\mathcal{H}$ is a Hilbert-space corresponding to the set of possible physical states of the molecule. The eigenvectors $\varphi_0, \varphi_1, \varphi_2, \ldots \in \mathcal{H}$ of H correspond to the so-called stationary states of the molecule, in which state the molecule has a definite energy-value, namely the eigenvalues $E_0 < E_1 < E_2 \ldots \in \mathbb{R}$, respectively, which are solutions of the eigenvalue equation: $H(\varphi_n) = E_n \varphi_n$ (we have ignored degeneracies for the sake of simplicity; for all of this, see an arbitrary textbook on quantum mechanics). The molecule can only emit and absorb photons of frequencies $\nu_{mn} = (E_m - E_n)/h$ (Bohr's frequency condition). If the wavelength $\lambda_{mn} = c/\nu_{mn}$ lies outside the visible spectrum, or if the intensity $I(\lambda_{mn})$ of this light lies below the eye's sensitivity-threshold $s(\lambda_{mn})$, then we do not see object X by means of this light. This is, however, a simplified description for at least three reasons.

First, what counts for observability of X is the total (emission and reflection) spectrum of X, for all wavelengths in the visible part, to which all the kinds of chemical substances which constitute X contribute. This total intensity is proportional to the relevant quantum-mechanical probabilities, which are determined by the states of the molecules, or better, by the state of the composite physical system X according to quantum mechanics. *Secondly*, the way the molecules bind each other is of importance. Metals have comparatively free electrons wandering through their molecule lattice, responsible for the conductivity of metals. But these same electrons are also responsible for the shiny appearance of metals (mirrors!), because they can, due to their comparatively free state, absorb and reflect very many wavelengths from the visible spectrum.

So in principle the emission-*cum*-reflection spectrum of every X can be calculated theoretically, but of course not in practice, notwithstanding the fact that quantum chemists have studied and do study the Hamiltonians of complex chemical compounds intensively. Such spectra can also be determined experimentally. They turn out to depend, *thirdly*, on the *temperature* of X. We should have written $I(T, \nu)$ rather than $I(\nu)$, or $I(T, \lambda)$ rather than $I(\lambda)$. If X is a chunk of iron at room temperature, its emission spectrum will look different from when it reaches its melting point. In fact, for each temperature a different spectral distribution obtains, but the dependence of the energy-density ϵ on the temperature T and the frequency ν is universal, in that it is the same for all known kinds of objects (Kirchhoff's law), provided we restrict ourselves to *black bodies* (objects that absorb all radiation that falls on them, such as the Sun or a cavity in an isolated solid body). The precise dependency is then given by Planck's celebrated radiation law: $\varepsilon(T,\nu) = 8\pi h\nu^3 c^{-3}(\exp[h\nu - k_B T] - 1)^{-1}$, where k_B is Boltzmann's constant.[20] The graph of $\varepsilon(T_0,\nu)$, for a fixed temperature T_0, is a curve with a single maximum at a frequency denoted by $\nu_{\max} = c/\lambda_{\max}$. When we look at the graph at a higher temperature, say $T_1 > T_0$, maximum $\lambda_{\max}$ shifts to a lower value. Their product, $T\lambda_{\max}$, remains constant (Wien's Displacement Law). The total intensity $I(T)$ of the radiation emitted by an object X at temperature T is obtained by integrating the energy-density $\varepsilon(T,\nu)$ over all frequencies, thus obtaining the Stefan-Boltzmann law, according to which the intensity of the emitted radiation is proportional to the fourth power of the temperature: $I(T) = \int_{\mathbb{R}} \varepsilon(T,\nu)d\nu \propto T^4$.[21] We finally remark that Planck's radiation law, and all its tested consequences, can be derived by quantum-statistical considerations about a 'gas of photons' in thermal equilibrium. This statistical way is the way to go when the number of molecules becomes too large for a quantum-mechanical molecule-by-molecule treatment—remember that one gram of hydrogen gas counts about 10^{23} H_2-molecules (Avogadro's number).

Hence we conclude that all the physical magnitudes of emitted and reflected light that are necessary and sufficient to know when it comes to questions of observability (wavelength, frequency and intensity) are determined by the properties of, and the relations between, the molecules that constitute the emitting or reflecting object and its temperature, and the properties of the energy-packets that constitute light. Quantum physics tells us how (and historically developed around precisely the issues of black body radiation and the production of light by atoms).

(v) To judge the observability of an object X, we take 'at a common survival temperature and pressure for X and $\mathcal{E}$' provisionally as a natural condition in Light$(X,\mathcal{E})$ of the Scientific Guide (19). For most medium-sized dry objects, room temperature and atmospheric pressure will be such a common survival temperature and pressure. The temperature scale for $\mathcal{E}$ at least includes the temperatures which human beings endure on planet Earth, ranging from

[20] For a careful, understandable and self-contained explanation of all these issues and how they gave rise to quantum physics, see Tomonaga ([1962], passim).

[21] This raises the question whether a macroscopic object (20) can become visible or invisible when we change its temperature within a range where the members of ε can survive. The answer is provided by performing a few elementary calculations using the laws mentioned and is negative.

about $-30°C$ (Siberia) to $40°C$ (Australia). The state of the art of technology determines how far we can go beyond this range of temperatures. But is *this* technology-dependence in the spirit of CE? Coherency seems to require that if observability is our ability to see with the naked eye, it must also be while having a naked body. This adds an erotic dimension to the concept of observability—perhaps turning CE into a 'sexy' view of science. This should not repel minds of a prudish inclination, because it is verifiably true that p sees X in the nude iff p sees X with clothes on (Nude), in spite of the fact that clothes are a product of human culture too, just as technological devices that will enable us to survive in conditions of temperatures lying far outside the interval $[-30, 40]°C$. But this is not the end of it yet.

Biconditional (Nude) is like the following statement, which is also verifiably true:

$$p \text{ sees } X \text{ with the window open iff } p \text{ sees } X \text{ with the window closed.} \tag{21}$$

But we cannot replace a window with a microscope, because in the latter case no such verification is possible. We then proceed by postulating objects on the basis of the images we see. Suppose we see a macroscopic (20) sample of solidified helium inside some high-tech isolation tank through a little window (assuming there is faint light inside the tank that leaves the solid aggregation state of the helium sample unaltered). In this case we cannot open the window, because the temperature inside the tank is about 10°K and the pressure is about 15,000 bars: as soon as we open the window (assuming we can do this, for the sake of argument), the sample evaporates in no time. Suppose we visit fish living in the deep black sea in a submarine able to withstand the water pressure and equipped with a searchlight, and see the fish through a window. Open the window and the pressure of the water will squeeze us like juicy lemons before we have a fair chance to drown. A third similar example is the Sun's core. The Sun is observable all right, but how about its core? The core is a very macroscopic object, bigger than the Earth. Suppose, again for the sake of argument, we penetrate the outer layers of the Sun in a super spaceship having windows (!) and reach its core. And again, opening the window, with an outside temperature of 4.5 million°C, inside a gigantic hydrogen bomb that is in a perpetual state of exploding, is not really an option. If we want to uphold biconditional (21), we certainly cannot verify it for these three mentioned examples—and live to tell.

These cases are more like the microscope case: seeing the helium sample or the Sun's core with the window open is simply not an option, just as seeing blood cells and microbes without a microscope is not an option. In the microscope case, the reason is that the objects are too small to be seen, whereas in the cases treated above, the reason is that in the nude we are too fragile to co-exist with the objects under consideration. Therefore it seems to make no sense to ask whether we see X, or do not see X, with our naked eyes in our naked bodies in these fatal conditions. This judgment is borne out whenever we consider the existence of X and $p \in \mathcal{E}$ at some common survival temperature and pressure as a *presupposition* of $\mathrm{Obs}(p, X)$.[22] The two conditions in (21) connected by 'iff' must have a common presupposition, which they do not have in the troublesome examples we presented above.

(vi) The sensitivity-threshold $s : \lambda \to s(\lambda)$ informs us how much energy per second is needed for the retina to send a signal to the brain and consequently for us to see some thing. Recall from (ii) that the intensity $I(T, \lambda)$ is the amount of energy per second per unit area. One obtains the total amount of energy per second of the light emitted and reflected by object X by integrating $I(T, \lambda)$ over the surface $S_X \subset \mathbb{R}^2$ of X. Suppose the distance between X and p is $d \in \mathbb{R}^+$. Introduce the *intensity-vector* $\vec{I}(T, \lambda) \in \mathbb{R}^3$, of magnitude equal to $I(T, \lambda)$ and direction pointing from the surface element $ds \subset S_X$ where the radiation originates to the eyes of p. Define $\vec{ds}$ as the vector perpendicular to ds, pointing outwards, of magnitude ds. Then the total amount of energy per second going in the direction of the eyes of p is obtained by integrating $\vec{I}(T, \lambda) \cdot \vec{ds}$ over S_X and discarding light emitted or reflected by the parts of S_X turned away from the eyes; at a distance d this amount is then reduced by dividing it by d^2, due to Gauss's law; call it

$$E(T, \lambda, S_X, d) \equiv d^{-2} \int_{S_X} \vec{I}(T, \lambda) \cdot \vec{ds}\, \Theta(\vec{I}(T, \lambda) \cdot \vec{ds}) \tag{22}$$

where $\Theta : \mathbb{R} \to \{0, 1\}$ is an adjusted Heaviside step-function (1 if its argument is positive, otherwise 0), securing that radiation going away from the eyes does not contribute. Now we no longer need constraints on the size of X in the Scientific Guide (19): if the size is such that $E(T, \lambda, S_X, d)$ is smaller than the sensitivity-threshold $s(\lambda)$, then p does not see X, otherwise p does see X, and that is the end of it.[23]

Let us summarise our elucidations in a criterion for observability.

> **Scientific Criterion.** On the presupposition there is temperature T and a pressure where object X and $p \in \mathcal{E}$ survive, $\mathrm{Obs}(X, \mathcal{E})$ iff
>
> $$\exists\, d \in [10\,\mathrm{cm}, R_@], \exists \lambda \in [400, 800]\ \mathrm{nm} : s(\lambda) < E(T, \lambda, S_X, d)$$
>
> where $R_@$ is the radius of the universe (about 156 billion light-years), $s : \lambda \to s(\lambda)$ is the sensitivity-threshold of the human eye, and $E(T, \lambda, S_X, d)$ is the total energy (22) of emitted-*cum*-reflected light of wavelength λ by (23)

[22] Presupposition is a subject in logic fully treated by van Fraassen, notably in his ([1971]), pp. 153–163.

[23] One can in fact calculate, given a spherically shaped object (call it O), a fixed distance of say $d = 10$ cm, a fixed light source, say the Sun, and $s(\lambda)$ of yellow light, what the radius of O must be in order for us to see it. The answer is of exactly the same order of magnitude as in Macro(O) (20). Good thing.

> object X having surface S_X at distance d from $p \in \mathcal{E}$. If there is no such common survival temperature and pressure for X and $\mathcal{E}$, we consider $\text{Obs}(X, \mathcal{E})$ to be indeterminate; and if there is but X transmits all visible light and neither reflects nor emits any (such as the invisible man), then we call X unobservable.[24]

Scientific Criterion (23) is free of modal and conditional (but not of presuppositional) talk, is not anthropomorphic (although anthropomorphically motivated), and is useful in that it contains information gathered by empirical inquiries and stored in scientific theories that can be compared with the description of the object X under consideration. The Context Problem and Psillos' Problem dissolve in the presence of the Scientific Criterion (23), because there is neither a general concept of a context needed, nor a quantification over contexts; therefore Criterion (23) improves on the Rough Guides of the Introduction (Section 1). The blunt fact that all the required scientific knowledge in order to apply Criterion (23) is *not* readily available for every X one comes up with, such as Hamiltonians and the solution of their eigenvalue problem for all chemical compounds, is annoying all right—and this makes Criterion (23) admittedly rather useless—, but this does not make it fundamentally flawed.

Hence we conclude that already we have gone beyond (Monton &) van Fraassen. How the Scientific Criterion also solves Musgrave's Problem we explain in Section 6. We next return to the Rough Guides and present a definition of observability that fits more naturally in the dialectic we reviewed in Section 1, and on top of that is useful.

4 A New Rough Guide and a definition

In the Introduction (Section 1), we met two Rough Guides to observability, both suffering from problems. We now propose a third Rough Guide, which is like van Fraassen's original but untenable Rough Guide (1) in that only extensional language is used, and is therefore unlike Monton & van Fraassen's problematic Modal Rough Guide (2):

> **New Rough Guide.** Concrete object X is *observable* iff there are circumstances which are such that X is present to us and we observe X.

We now define observability precisely by translating this New Rough Guide in the language of the wave theory of light, which encapsulates the scientific

[24] If we can feel the invisible man by touching him, then he is only unobservable by virtue of us having equated observability with visibility. Needless to say, the invisible man, the cloaking devices of spaceships from Star Trek, etc. are very much science *fiction*: changing molecules such that their absorbtion- and reflection-probabilities become so radically different means, according to quantum mechanics, changing their Hamiltonians, and therefore most of their other properties as well, some of which undoubtedly are necessary for the molecules constituting the complex compound systems that they do.

knowledge relevant here:

Definition. $\mathrm{Obs}(X, \mathcal{E}, \mathbf{L})$ iff

$$\forall p \in \mathcal{E}, \exists \mathcal{M} \in \mathbf{L}\colon\ \mathrm{tr}(\mathcal{M},\ \mathrm{Front}(p, X) \wedge \mathrm{Sees}(p, X)) \qquad (24)$$

We next proceed by making a number of systematic remarks, in order to elucidate this definition further and to make the case that it is good.

(i) The very first question to ask is whether definition (24) saves all the relevant linguistic phenomena. Consider the following statements:

- A point in a piece of printed text is observable.
- A living Tyrannosaurus is observable.
- Electrons are unobservable.
- The moons of Jupiter are observable. (25)
- Black holes are unobservable.
- Pegasus is observable.
- Kelvin's knot-molecules are unobservable.

A particular dot, such as the point on this 'i', is a small actual object we can see; call it D. Let p be an arbitrary member of $\mathcal{E}$. There is some model $\mathcal{M} \in \mathbf{L}$, even an actual one, describing the situation of the black, light-absorbing object D on a light-reflecting (white) background, and some light source S emitting light of a particular intensity falling on D, such as the sun or a lamp. In $\mathcal{M}$ the eyes of p (e_p) are positioned 20 cm, say, in front of D. So $\mathcal{M}$ makes Front (p, D) true by construction. By applying the regularities of ray-optics, which follow from **L**, we can draw the image of the point on the retina of e_p, after the reflected light from the white paper has been refracted through the lens of e_p. The intensity of the light falling on the retina, forming an image of D, lies far above the sensitivity-threshold of e_p, and the image is larger than the resolution-power of the retina, which is to say that $\mathcal{M}$ makes $\mathrm{Sees}(p, D)$ true.

Admittedly this is only a qualitative sketch. But it ought to be clear that when particular numbers are put in (intensity of the light source, etc.), the *definiens* of (24) will be satisfied. This is beyond doubt and this is sufficient for our present purposes because we now can safely conclude that dot D, a point in printed text, is observable.

Similar arguments involving models of **L** can be given for all objects occurring in (25). For a living Tyrannosaurus, *vide* Spielberg ([1993]). Electrons and Kelvin's knot-molecules are so tiny that light 'does not see them' in the same sense as a tidal wave 'does not see' a grain of sand. Black holes are unobservable for a reason which is suggested by the very name that J. A. Wheeler honoured them with.[25] We now simply conjecture that if a

[25] Although black holes are objects whose existence can only be explained by the general theory of relativity, they can be modelled in **L**: as *black bodies* of a spherical shape having a radius equal to the Schwarzschild radius.

definition of observability can save the seven linguistic phenomena in (25), it can save them all.

(ii) With the aid of (i) it is easy to see that the Scientific Criterion of observability (23) is co-extensive with definition (24). If an object is macroscopic and its emitted-*cum*-reflected spectrum lies above the sensitivity spectrum of the human eye, then we see it when standing in front of it in broad daylight, which we can easily model in **L**, so that the Obs(X, $\mathcal{E}$, **L**), and *vice versa*. What about the presupposition of Scientific Criterion (23)? The most expedient thing to do at this juncture is to consider it as a presupposition also of definition (24).[26]

(iii) Pegasus and the headless horseman are fictional objects big enough to be seen by us (9). We can easily construct a model from **L** of $p \in \mathcal{E}$ being in front of Pegasus and seeing this horse with wings. From this we see that definition (24) vindicates that the observability of an object is independent of its existence, i.e. whether it is real or not (9).

(iv) How about fish living in the deep black sea? They are harmless, for we can construct a model $\mathcal{M} \in \mathbf{L}$, wherein they swim in an aquarium, so that every such macroscopic fish is in front of an arbitrary member $p \in \mathcal{E}$ and sees it veridically. Then $\mathcal{M}$ makes Front(p, fish) and Sees(p, fish) true, which is to say that according to definition (24) the fish is observable.

(v) On the one hand, van Fraassen claims that observability is a subject for scientific research and not for philosophical analysis ([1980], p. 57; Monton & van Fraassen [2003], p. 413), and that 'in practice, we must rely on our current best *theories* to answer the question' ([2003], p. 414), whereas on the other hand he required that observability must be *theory-independent* in order to avoid a vicious 'hermeneutic circle' in CE ([1980], pp. 57–8), which hints at Musgrave's problem: if the epistemic policy of CE tells us what the proper epistemic attitude is towards theories, then it should not rely on a theory-dependent distinction. Fire and brimstone from Monton & van Fraassen ([2003], p. 412, our italics):

> The very first obstacle is that for a philosopher to identify the contingent factors in general that constitute observability in general would run precisely counter to van Fraassen's contention that *what is observable is an empirical question*. Given this view, any such philosophical enterprise must end up as *armchair science*—worst in the empiricist's catalogue of *philosophical sins*, next to psychologism—or as *metaphysics of the same ilk as Modal Realism*.

[26] Another way is to enrich $\mathcal{L}_\mathbf{L}$ with the predicates temperature and pressure, to consider every object X to be accompanied by a temperature- and a pressure-range, and to quantify in (24) over the subset of models in **L** that all make the following sentence true: the intersections of the temperature-ranges of X and $p \in \mathcal{E}$, and of their pressure-ranges are both not empty.

We *seem* to be in trouble, because our definition of observability (24) depends on scientific theory **L** and the Scientific Criterion (23) is charged with theory, either **L** or the quantum theory of radiation. *Seem*, because Monton & van Fraassen are in trouble, and not us, as we shall see after having climbed the following ladder.

Rung 1. Monton & van Fraassen ([2003], p. 409) express their fear that *if* observability were theory-dependent, two different theories might produce conflicting judgments about the observability of some object. *We* never heard of two *accepted* scientific theories such that one theory judges an object to be observable and the other the same object to be unobservable. Moreover, if there were two *accepted* theories, and some particular real object, *Y* say, were observable according to one theory but unobservable according to the other, then at least one of these theories would be empirically inadequate (which can be decided by taking a look at *Y*), although any constructive empiricist would have to believe that these two theories are empirically adequate whenever accepting them. Thus the situation envisioned by Monton & van Fraassen not only does not occur but even *cannot* occur, not even by modest constructive-empiricist lights. We conclude that their fear is irrational.

Rung 2. Experimental research is fundamentally incapable of discerning between unreal observable, unreal unobservable and real unobservable objects, because in all three cases we see nothing (cf. Muller [2004], pp. 95–6). From every experiment where test persons are asked whether they see some putative object *Y* under a variety of circumstances and they answer in the negative, one can only conclude the disjunction of the three mentioned mutually exclusive cases. But when the question whether object *Y* is observable is a scientific question and experimental inquiry is incapable of helping us any further, then the only place in science left to go to is where *theories* live.

Rung 3. There is no threat of a vicious 'hermeneutic circle' when we rely on **L** to tell us that *X* is observable or that *X* is unobservable. For **L** is not the only scientific theory that CE is about—CE is about *all* scientific theories. Moreover, **L** says *much* more than that an object is observable or not; in fact, it is everything else that has historically provided the basis for the acceptance of **L** by the community of physicists and it still does so for us today. True, CE assigns a privileged status of sorts to theory **L**, but that is a direct consequence of the privileged epistemic status CE assigns to actual observables, in good empiricist tradition. The vicious hermeneutic circle is a *fata morgana*.

Rung 4. Van Fraassen says ([1980], p. 14) that

> all our language is thoroughly theory-infected. [...] This is true also, as Duhem already emphasised, of experimental reports. Hygienic reconstructions of language such as the positivists envisaged are simply not on.

But then, *mutatis mutandis*, the sharp distinction that van Fraassen tacitly draws between, on the one hand, scientific theory, and, on the other hand, scientific research and empirical inquiries disinfected from theory is not on either.

Rung 5. We must rely on our current best theories 'in practice', Monton & van Fraassen say. There you go. No fear of theories in practice. But we must not rely on our current best theories 'in principle'? For the principled matter, is there an even more reliable basis for answering the question than our current best theories? What might that be? Final Science. Yet Monton & van Fraassen (ibid.) also say they don't believe that 'ideally rational scientific inquiry will someday end'. There never will be a Final Science. The 'principled criterion' allegedly revealed by Final Science is more like a 'never-never criterion'. Completely useless it seems. Why can we not lift our criterion (24) to the status of a principled one? Whenever in the future certain revisions to **L** will prove necessary in the light of newly discovered phenomena, then we shall investigate whether criterion (24) needs revision too. If it does, we shall be glad to make the necessary revisions. If the principled criterion *is* a fruit of scientific inquiry, *then this is how things ought to be*.

Rung 6. What if we say that observability is some relational property of object X to $p \in \mathcal{E}$ and that science approximates it better and better as science progresses, that the former is the principled side of observability and the latter the practical side, and that the current best approximations are definition (24) and criterion (23), thus only concerning the practical side? If this means that the principled matter is a matter of *a priori* metaphysical postulation that poor science can only *approximate* but never obtain, then this smells like the kind of metaphysics that CE wants to do entirely without. If it is up to science to tell us what observability is, then there is *nothing but* the 'practical side'. The principled side is a metaphysical mirage.

Rung 7. Suppose, for a moment, that we are in the Never Never Land of Final Science, then what? Since **L** is as far as we know an empirically adequate theory that deals with the behaviour of light when it comes to seeing things, Final Science must be able to reproduce the empirical success of **L**. So Final Science must contain a part that is empirically equivalent to **L**, certainly up to the level of experimental accuracy that is sufficient for our present purposes—and which **L** meets. Then *in particular for an empiricist* the choice between a principled definition of observability in terms of the concepts of Final Science and the one in terms of **L**, i.e. definition (24), is epistemically like the choice between six of one and half a dozen of the other. Hence even in Never Never Land there is not a pin to choose between the alleged principled criterion and criterion (24).

Rung 8. Scientific research has results—it better had! The empirical inquiries into the observability of objects were pursued actively in the 1950s and 1960s and came to an end (or a provisional end) some time ago. Enough results had apparently been gathered. (All currently flourishing research into the human eye is research about the cognitive capabilities of the visual system as a whole and about where precisely in the brain things happen that are relevant for seeing, and where and how 'visual information is processed'. Which objects are visible under which circumstances—the only relevant question for us—is now a depleted area of research.) Why, then, not try to extract a useful definition of observability from the results of these inquiries? This is not 'armchair science', let alone 'metaphysics of the same ilk as Modal Realism'. Not in a million years. This is drawing philosophically relevant conclusions from empirical inquiries. It is armchair *philosophy* all right (armchairs being the eminent place where most philosophy is conducted, as well as logic, mathematics and theoretical physics, by the way), but it is also philosophy *based on the results of precisely the empirical inquiries that according to van Fraassen are the only legitimate source of information concerning observability*. Do Monton & van Fraassen only want to pay lip-service to science or are they prepared to get down to it? Or is there today still something unknown that we absolutely must investigate scientifically before we can decide whether an object is observable? Once more, most if not all 'contingent factors' were identified some time ago and are lying there for the taking. Why let them lie waste?

Having climbed the ladder, we conclude that by relying on the results of the relevant empirical inquiries and on the relevant accepted scientific theories wherein the results of such inquiries find a home, in particular in **L** and the quantum theory of radiation, we have proceeded in harmony with the spirit if not with the letter of CE. This neither prevents us from saying that observability is an objective relation between objects and the light-detectors of the members of $\mathcal{E}$—quite to the contrary, we can say it in good scientific conscience—, nor traps us in vicious circles within the confines of CE. van Fraassen's fear of reliance on a scientific theory is misconceived.

5 The Context Problem and Psillos' Problem

Recall that the Context Problem arose for the Modal Rough Guide (2): the concept of context was left unacceptably foggy and general in order to be used in clear arguments and to be a pillar of the epistemic policy of CE. And in so far as it was neither unacceptably foggy nor too general, from where will Monton & van Fraassen obtain their 'good deal of unformulated general opinion' and 'features specific to the case' (3)? When dealing with such specific subject-matters massively inquired into by science, we should base judgements involving these matters on the results of the scientific inquiries, and surely not on the results of polls organised to find out what 'general opinion' is. Right? In *science* we generally find a reliable basis for drawing inferences about the world. This is, to repeat, exactly what we have done: the results of these inquiries are stored in **L** (18) and are made manifest in the Scientific Criterion (23) as well as in definition (24), which are co-extensive. We therefore conclude that we have succeeded in improving upon the too foggy and too general 'good deal of unformulated general opinion' and 'features specific to the case' by means of the rigorously delineated models in **L**. The Context Problem arises neither from definition (24), where 'context' can be said to be replaced with 'model of **L**', nor from the Scientific Criterion (23), where 'context' can be said to be replaced with a simple presupposition.

We call to mind that Psillos' Problem was how to distinguish 'permitted' from 'forbidden' context when adopting the Rough Guides of van Fraassen we discussed in the Introduction (Section 1). One can see **L** (18) as legislator, separating the 'permitted contexts' from the 'forbidden' ones: the permitted ones are exactly the models of **L** (18); everything else is forbidden. A fictional object like Psillos' microman is unobservable, because there are no models in which members of $\mathcal{E}$ see microman with the naked eye, simply because microman is too small. Microman himself is not a member of $\mathcal{E}$. *His* eyes do not occur in the models in **L** (18); by definition only the eyes (e_p) of the actual members of $\mathcal{E}$ appear in these models. Since $\forall$ in definition (24) ranges over $\mathcal{E}$, whatever microman can see and cannot see has no effect on what is observable, any more than what a cat and a bat can and cannot see. Pancake-sized blood cells are, of course, observable fictional objects, on a par with other fictional objects like Pegasus and the headless horseman—that was never really a problem. Psillos' Problem is solved. And *mutatis mutandis* for the Scientific Criterion (23).

6 Musgrave's Problem

As we succinctly explained in the Introduction (Section 1), Musgrave pointed out that a constructive empiricist cannot think that it is True that electrons, say, are unobservable because '$\neg\text{Obs}(e, \mathcal{E})$' is not empirical, and thus he must adopt a neutral epistemic attitude towards '$\neg\text{Obs}(e, \mathcal{E})$'. A constructive empiricist cannot believe that electrons are unobservable! Musgrave's Problem was thus how it is possible to acquire, for every concrete object X, the belief that X is observable or the belief that X is unobservable. The key to the solution is a slight revision of the epistemic policy of CE.

Van Fraassen's extant epistemic policy is for propositions of accepted scientific theories. Recall that we defined proposition ψ to be *empirical* iff ψ is only about real observable objects or real images, or both (Section 2). The epistemic policy of CE prescribes belief in the Truth of an accepted proposition, ψ say, whenever ψ is empirical, and remaining neutral with regard to the

Truth and the Falsehood of ψ otherwise. We now propose the following revision for observation propositions. Definition (24) gives Truth-conditions for $\mathrm{Obs}(X, \mathcal{E}, \mathbf{L})$ which are verifiable as soon as X is sufficiently specified—according to the Scientific Criterion (23) we only need to know the size of X, its emission spectrum and under what thermal and pressure conditions it exists. Nothing prevents us now from saying that the constructive empiricist should believe that X is observable iff $\mathrm{Obs}(X, \mathcal{E}, \mathbf{L})$ is True; and believe that X is unobservable iff $\mathrm{Obs}(X, \mathcal{E}, \mathbf{L})$ is False. Musgrave's Problem is hereby solved.

7 Modality without inflationary metaphysics

Modality according to Constructive Empiricism. For the sake of future reference and to have an idea what we are talking about, we begin by adding a few examples to the so-conditionals in (8) so as to obtain the examples of modal talk in science listed below.

(C) If Bas *were* 1 km from the surface of Callisto in his flying saucer and *were to look* through the window, he *would not see* this moon of Jupiter.
(D) If James *were to stand* in front of a living Tyrannosaurus in a typical Jurassic landscape in broad daylight with his eyes wide open, he *would not see* this enormous reptile. (26)

(E) When a piece of dry paper is lit (in the air), it will *necessarily* burn.
(F) The fact that the best-adapted species will survive in the long run is a biological *necessity*.
(G) A perpetuum mobile of the second kind, which is a machine that produces more mechanical work than it consumes energy, is a physical *impossibility*.
(H) Bricks *necessarily* fall downward when dropped (near the surface of the Earth). (27)
(I) It is *impossible* to prepare a quantum-state having an indeterminacy in position and momentum such that their product is smaller than $\hbar/2$.
(J) The mass of the electron in Dirac's relativistic wave-mechanical theory of the electron is a *contingent* matter.
(K) The spectrum lines of a helium atom *necessarily* split in the presence of a magnetic field.

So-conditionals (C) and (D) should come out False and (E)–(K) should come out True on any viable account of modality. Further, so-conditionals (A) and (B) in (8) should come out as True.

From the various papers and Chapters in books of van Fraassen ([1975]; [1977]; [1980], pp. 196–203; [1981]; [1989], pp. 65–8), and from Monton & van Fraassen's ([2003]) reply to Ladyman ([2000]), there emerges the following view on modality. In order for CE to ground its claim that CE makes sense of science, CE must tell us how to understand modal propositions that occur in science, e.g. the ones in (27); this includes telling us how to reason with them and to provide them with a semantics. This is a project for the philosophy of language, not for metaphysics. An empiricist account of modality must in particular not rely on Modal Realism, because this is a shining example of anti-empiricist 'inflationary metaphysics', transcending experience to a bizarre extent. van Fraassen ([1989], p. 68) speaks about 'a robust denial that there are other possible worlds—for possible-world talk is then only a picturesque way to describe models'. For van Fraassen ([1980], p. 202), the locus of modality occurring in science lies in the models of accepted scientific theories. Thus the programme of CE is to replace the metaphysical entity of a possible world with the abstract entity of a model, and then to engage in some modal logic within the semantic view of scientific theories.[27] If and when the programme succeeds in reducing every modal proposition in science to some non-modal proposition in the framework of the semantic view—or explains how this in principle can be achieved—then all modal propositions can be treated semantically on an equal footing with their extensional brothers and sisters.

To summarise, we consider this programme successful iff we can answer Questions [**a**]–[**c**] below.

> [**a**] What are the nominalistically respectable meanings of the notions of possibility, necessity, contingency and the subjunctive conditionals?
> [**b**] How to reason with modal propositions? (28)
> [**c**] What is the epistemic policy of CE for modal propositions?

Before we begin to answer Questions [**a**]–[**c**], a final remark. In their response to Ladyman, Monton & van Fraassen say that their view on modality is what Ladyman called *modal non-objectivism*, which is the view that modal statements have non-objective Truth-conditions ([2003], p. 416): 'Modal statements can be considered to be true or false, but only relative to a context'. We point out here that van Fraassen's assertion that consequently objectivity is lost for modal statements is due to his weirdly taking (Obj) context-independence as a necessary condition for objectivity (cf. Section 1, the paragraph below (3)). We shall demonstrate that 'context' can be replaced with a model or a subset of models of an accepted theory, or with an accepted theory, which has little if anything to do with a loss of objectivity—on the contrary.

[27] One may object that the abstract objects in the universe of discourse of set-theory (unobservables) also transcend experience to a bizarre extent. True, but since mathematics is indispensable for science and all mathematics used in science can be reduced to set-theory, we are already committed to *accepting* $\mathbf{V}_{\omega+\omega}$ anyway (cf. footnote 13). Certainly, a view of CE on mathematics and abstract objects ought to be developed, but not in the current paper; we conjecture that remaining neutral *qua* belief with respect to $\mathbf{V}_{\omega+\omega}$ and all its inhabitants will prove the most natural epistemic attitude for CE because they are non-eliminable unobservables. Cf. Bueno ([2000]). Possible worlds are eliminable, so an anti-realist attitude is the right epistemic propositional attitude for a constructive empiricist here.

[**a**,**b**] *Modal Logic* is a branch of logic that has its origins in philosophy, in particular in the ground-breaking work of C. I. Lewis (and C. H. Langford) who wanted to solve 'the paradoxes of implication' and did so by introducing the concept of 'strict implication' and the monadic modal operator $\Diamond$ for 'it is possible that'. Blackburn *et al.* ([2001]) show in their recently published tome on modal logic, which is packed with results obtained since the 1920s, how the subject has gone far beyond purely philosophical concerns and has found numerous applications in model theory, linguistics, computer science and complexity theory, and has been fertilised in turn by developments in those fields of inquiry.[28] Questions [**a**,**b**] (28) are answered iff we can lay down axioms or definitions for the mentioned modalities, rules for how to reason with them and truth-conditions for modal statements in science, provided we stay away from inflationary metaphysics or metaphysics of the pre-Kantian kind, such as possible-world semantics. One way to proceed would be to pick and choose from modal logic without any philosophical constraints and then simply to deny any ontological responsibility (see footnote 28). Such a way of proceeding would be in harmony with how van Fraassen proceeds when it comes to scientific theories and their use of the unobservable abstract entities of mathematics. But van Fraassen prefers, as a card-carrying nominalist, something epistemologically stronger than a neutral propositional attitude with respect to possible worlds, namely a robust denial: anti-realism.[29] Then he must, like Goodman and Quine in the past and H. Field in the present, show how to make sense of modality in science without in particular possible worlds. This is what we do next.

For the sake of simplicity, we confuse propositions, statements in a language that express propositions and well-formed formulae (those with free variables can always be closed by universal quantification to become statements expressing propositions). We recall that the beating heart of the semantic view is the conception of a scientific theory, **T** say, as a set of models $\mathcal{M} = \langle \mathfrak{S}, \mathcal{S}, R, v, \Phi \rangle$ (10). Think now of $\Phi \in \mathcal{M}$ as the set of statements expressed in a particular first-order language, the rigorous catch of what scientists would call the 'language of **T**'. Now enrich this language with the monadic

[28] Beall & van Fraassen's new book on modal logic ([2003]) is much more modest and aims to introduce philosophy students to modal and many-valued logic. In this book all semantics proceeds in terms of possible worlds; its authors explicitly reject any ontological responsibility for this commitment, in footnote 6 on p. 53. In Blackburn *et al.* ([2001]), possible-world semantics is but one kind of semantics for modal logics. Our semantics will proceed within the semantic view on scientific theories, absent from both of these books, and this absence provides the warrant for Section 7 of the present paper. Parenthetically, Blackburn *et al.* speak of The Syntactic Era (1916–1959), The Classical Era (1959–1972) and The Modern Era (1972–now) in the development of modal logic ([2001], pp. 37–48). Beall & van Fraassen ([2003]) is mainly devoted to The Syntactical Era and the Classical Era.

[29] See above. Van Fraassen ([1985], p. 303): 'I am a nominalist.'

modal operator $\Diamond$, where we shall interpret $\Diamond\varphi$ as 'it is possible in this model $\mathcal{M}$ that φ', for $\varphi \in \Phi$. All other relevant modalities can be defined in terms of $\Diamond$ by means of the following definition-schemas:

$$\begin{array}{llccc} \text{necessity} & : & \Box\varphi & \longleftrightarrow & \neg\Diamond\neg\varphi \\ \text{contingency} & : & \triangle\varphi & \longleftrightarrow & \Diamond\varphi \wedge \Diamond\neg\varphi \\ \text{were-would} & : & \varphi \,\Box\!\!\rightarrow \psi & \longleftrightarrow & \Box(\varphi \rightarrow \psi) \wedge \Diamond\varphi \\ \text{were-might} & : & \varphi \,\Diamond\!\!\rightarrow \psi & \longleftrightarrow & \Diamond\varphi \rightarrow \Diamond(\varphi \wedge \psi) \\ \text{strict cond.} & : & \varphi \hookrightarrow \psi & \longleftrightarrow & \Box(\varphi \rightarrow \psi) \end{array} \tag{29}$$

Notice that the definition-schema of the would-conditional will make counterfactuals with an impossible antecedent vacuously false, rather than vacuously true as some philosophers prefer. The question of how many axioms we should take on board in order to have a sufficiently strong deductive system that can cope with all modal expressions in science can only be answered by a thorough investigation into the use of modal concepts by scientists. Our intuition says that neither double modalities nor switching of modalities and quantifiers is needed (which circumvents taking issue with the Barcan-formula), in which case the normal modal logic M seems the appropriate candidate: in addition to the Aristotlean definition-schema for $\Box$ above (the dual of $\Diamond$) and the deduction-rules of propositional logic (which are included in those of first-order predicate logic), it has one extra deduction-rule, namely the rule of generalisation: if M $\vdash \varphi$, then M $\vdash \Box\varphi$ (every modal-logical theorem is a modal-logical necessity). Further, M has as additional axioms to the ones of propositional logic:

$$\begin{array}{ll} \text{Distribution}: & \Box(\varphi \rightarrow \psi) \rightarrow (\Box\varphi \rightarrow \Box\psi) \\ \text{Actuality}: & \varphi \rightarrow \Diamond\varphi \end{array} \tag{30}$$

Distribution distributes $\Box$ over the antecedent and consequent; it is a sort of *modus ponendo ponens* for a $\Box$-prefixed material conditional and its antecedent. Actuality is self–evident: what is the case is possible. Familiar and desirable theorems, such as $\Box\varphi \rightarrow \varphi$, then follow.

The admissability of the valuation $v : \mathcal{S} \rightarrow \wp\Phi$ concerning modalities consists in this single requirement:

$$\Diamond\varphi \in v(\mathcal{S}) \longleftrightarrow \exists\, r \in \mathcal{S} : sRr \wedge \varphi \in v(r) \tag{31}$$

which leads to tr$(\mathcal{M}, s, \Diamond\varphi)$ iff tr$(\mathcal{M}, r, \varphi)$ for some state $r \in \mathcal{S}$ related to s. This is precisely how things proceed in modal logic generally, where $\langle \mathcal{S}, R\rangle$ is called a 'frame' for the model $\mathcal{M}$. All modal logics used in philosophical logic are sound and most of them are complete too (cf. Blackburn *et al.* [2001], Ch. 4). The frame-relation R determines the class of modal-logical truths (modal tautologies): if R is reflexive, Actuality (30) is a modal tautology (Distribution always is).

We now can talk modally in the context of a single model $\mathcal{M}$ but we cannot go beyond, although in the light of examples (27) we must go beyond. Indulge us to illustrate this distinction, between model-based modalities and theory-based modalities, with an example.

Suppose we have some quantum-mechanical model of some physical system, a single helium atom say; call it $\mathcal{M}$(He). Then $\mathcal{S}$ is some Hilbert-space $\mathcal{H}$. Suppose at time $t_0 \in \mathbb{R}$ the helium atom is in state $|\psi_0\rangle \in \mathcal{H}$, and that the solution of the initial value problem for the Schrödinger-equation is the continuous, connected Abelian Lie-group of unitary operators, $\mathcal{U} : t \mapsto \mathcal{U}(t)$, acting on $\mathcal{H}$, so that $|\psi(t)\rangle = \mathcal{U}(t)|\psi_0\rangle$. An obvious definition of the accessibility relation between states is as follows: $|\alpha\rangle R|\beta\rangle$ iff there are two moments in time, $t_1, t_2 \in \mathbb{R}$, such that $|\alpha\rangle = |\psi(t_1)\rangle$ and $|\beta\rangle = |\psi(t_2)\rangle$. This yields that only states which are solutions of the Schrödinger-equation are *possible* in $\mathcal{M}$ (He)—which seems exactly the right thing to say. This also yields that only states in $\mathcal{H}$ which can be connected to $|\psi_0\rangle$ by a continuous path in $\mathcal{H}$ are *accessible* for this physical system in this model—which again seems exactly the right thing to say. And this also yields that the probability for finding a value for physical magnitude energy $H : \mathcal{H} \to \mathcal{H}$ in Borel set $\triangle \in B(\mathbb{R})$ at time t_3, denoted by $\Pr(H, t_3; \triangle)$, *would* be different from the current probability, determined by $|\psi(t_3)\rangle$, if at time t_0 the state *were* different from $|\psi_0\rangle$—which again seems exactly the right thing to say (the curve in $\mathcal{H}$ remains the same, because there time-translation invariance is a dynamical symmetry). All these right things to say are made true in $\mathcal{M}$(He). In general, for physics, to tie up the accessibility relation on the states of a physical system with the solution of the relevant dynamical equation seems exactly the right thing to do. Usually this leads to an Abelian dynamical group, which turns the accessibility relation into an equivalence relation—and this in turn leads to a large class of modal-logical tautologies.

But now suppose we want to say: if we had turned on a magnetic field, the helium atom would have behaved differently, in that at time t_3 the probability $\Pr(H, t_3; \triangle)$ would have been different (Zeeman effect). This we cannot express when we remain in $\mathcal{M}$(He), because we now need a different Hamiltonian, say H', hence a different model and a different probability, $\Pr(H', t_3; \triangle)$. The frame $\langle \mathcal{H}, R\rangle$ also changes, because R was defined in terms of the solution of the Schrödinger-equation, and this solution also changes when the Hamiltonian changes. What we now need is an accessibility relation on the models of quantum mechanics, where each model then plays the modal-logical role of a state.

In general, we should construe a theory **T** not only as a set of models $\mathcal{M}$ (10) but as such a set with an accessibility relation on it, say R_{T}. Our syntactic use of all model concepts (29) can stay put, but the semantics will change. Which is what we expect because now we are talking about what is *quantum-mechanically possible* and *necessary*, according to the theory, which comprises all models, and not within the confines of a single model. But it is also defensible to consider a multitude of accessibility relations on **T**. For suppose we want to consider the quantum-mechanically possible behaviour of a helium atom in various circumstances. Then only that set of quantum-mechanical models is relevant (accessible) which models a helium atom in all these circumstances—models of uranium atoms, Bohm-singlets, etc., can be discarded.

Generally speaking, we should and we can pick and choose a relevant accessibility relation at the level of the theory (all models), at the level of a sub-theory (a subset of models of **T**), or at the level of a single model. Not anything is possible, however, because the language of scientists in use puts constraints on what we can sensibly define. *That* use of language should be our guide in defining accessibility relations sensibly when we want to make sense of science.

Saving the Linguistic Phenomena. Let us now look whether the definitions save the linguistic phenomena (E)–(K) in (27). Examples (E) and (F) in (27) can easily be taken care of, because in these propositions the modalities arguably are *flatus vocis*; they can easily be re-formulated without changing the meaning *in any scientifically significant sense*:

(E′) When a piece of dry paper is lit (in the air), it never happens that it does not burn; it always burns. (32)

(F′) Biological mechanisms determine that the species best adapted to a particular environment will survive in the long run in that environment.

The translations of the other four examples non-trivially invoke definitions (29) and the admissibility-requirement on the semantics (31).

(G′) *No* model of Thermodynamics makes it true that some device produces more mechanical work than it consumes energy.

(H′) In *all* models of Newton's universal theory of gravitation in which *only* the Earth occurs and masses of about 1–10 kg ('bricks') are let go of above its surface (not higher than a few km, say), these masses follow a trajectory toward the centre of the Earth.[30] (33)

(I′) *Every* model of standard quantum mechanics wherein a physical system is prepared in some state makes it true that this state is always such that the product of the indeterminacies of position and momentum is larger than or equal to $\hbar/2$.

(J′) In some models of Dirac's relativistic wave-mechanics, we can set the value of the mass of the electron equal to a value different from its actual one without thereby leaving this theory; so '$m_e = 9.109558 \times 10^{-31}$ kg' is made true by some models, among which are all actual ones, and made false by others. (34)

[30] Notice that the italicized *only* circumvents the notorious problem of *ceteris paribus*-condition.

Example (K) we have dealt with above, in passing: an accessibility relation at the level of a subset of all quantum-mechanical models, namely those modelling a helium atom in various circumstances, leads to a necessity operator that makes statement (K) true. On that subset one can choose the universal relation for the accessibility relation.

A word on the concept ofz *physical necessity*, a notion different from our theory-bound necessity (29) and a welcome guest at realist tea parties. We claim that whenever a physicist speaks about 'physical necessity', he tacitly has some accepted theory in mind. We know that what is true in all models of one theory, say the Schrödinger-equation in standard quantum mechanics, is false in the models of another theory, say of relativistic wave mechanics, where relativistic wave-equations such as the Klein-Gordon, the Proca, the Kemmerer or the Dirac equation are true. In models of the general theory of relativity, light always bends along heavy objects, but never in models of wave optics. Moral: *one theory's necessity is another's impossibility*. 'Physical necessity' is an ambiguous phrase. When a scientist asserts a necessity-statement, it is usually possible to disambiguate it and make the theory she has in mind explicit.

One could, however, define the *physical necessity that* ψ as necessity according to *all* relevant currently *accepted* theories, in whose language we can express ψ. For example, falling stones when dropped are a physical necessity because all relevant models of both accepted theories of gravity that we have, Newton's theory of universal gravitation and Einstein's general theory of relativity, make it true. And *mutatis mutandis* for physical possibility.

Let us finally turn for a moment to the subjunctive conditionals, whose semantics follow from the definitions in (29) and the modal admissability requirement on the semantic valuation (31). Elsewhere van Fraassen wrote that 'scientific propositions are not context-dependent in any essential way, so if counterfactual conditionals are, then science neither contains nor implies counterfactuals' ([1980], p. 118). Now what? Well, van Fraassen means here by 'scientific proposition' *not* a proposition, True or False, considered by scientists *qua* scientists (as we do), but something much stronger: propositions implied by some accepted theory or made true by all models of an accepted theory (∗), because then, and only then, can one uphold that scientific propositions are not always of the subjunctive kind. But then, as discussions about verifiability and falsifiability have taught us, scientific theories make few if any factual assertions either, because for that one always needs boundary conditions, initial conditions, parameter-values, auxiliary assumptions and what not. On construal (∗), no scientific proposition has any empirical content and *a fortiori* the epistemic policy of CE only applies to empirically empty propositions. This is empiricism gone mad. Something has gone wrong here and that is the subscription to (∗). Reject it (and adopt our notion of what a scientific proposition is), and then scientific theories, when construed in accordance with the semantic view, do tell us whether relevant subjunctive conditionals are true or false.

Observability we have defined in non-modal language (24). Now we are also in a position to say what it means to state that *it is possible for us* to be in front of an object and see it; call this a *possibility observation proposition*, or *po-proposition* for brevity. By comparing definitions (24) and (29) we see immediately that observability propositions and po-propositions are co-extensive:

$$\mathrm{Obs}(X, \mathcal{E}, \mathbf{L}) \longleftrightarrow \forall p \in \mathcal{E} : \mathrm{tr}(\mathbf{L}, \Diamond(\mathrm{Front}(p, X) \wedge \mathrm{Sees}(p, X))) \tag{35}$$

Good thing.

Definitions of so-conditionals (8) and (26) arise by application of the general definition (29):

$$\begin{aligned} &\mathrm{tr}(\mathbf{L},\ \mathrm{Front}(p, X) \,\Box\!\!\rightarrow\ \mathrm{Sees}(p, X)) \longleftrightarrow \\ &[\forall \mathcal{M} \in \mathbf{L} : \mathrm{tr}(\mathcal{M}, \mathrm{Front}(p, X) \longrightarrow \mathrm{Sees}(p, X)) \\ &\quad \wedge\ \ \exists \mathcal{M}' \in \mathbf{L} : \mathrm{tr}(\mathcal{M}', \mathrm{Front}(p, X))] \end{aligned} \tag{36}$$

We submit that in the case of subjunctive observation-conditionals (so-conditionals), **L** gives us Truth-conditions:

$$\mathrm{Tr}(\mathrm{Front}(p, X) \,\Box\!\!\rightarrow \mathrm{Sees}(p, X)) \longleftrightarrow \mathrm{tr}(\mathbf{L},\ \mathrm{Front}(p, X) \,\Box\!\!\rightarrow \mathrm{Sees}(p, X)) \tag{37}$$

Let us now look at our prime examples of so-conditionals: (A) and (B) in (8), and (C) and (D) in (26). Consider (A):

$$\mathrm{Front}(\mathrm{James},\ \mathrm{Tyr.}) \,\Box\!\!\rightarrow \mathrm{Sees}(\mathrm{James},\ \mathrm{Tyr.}) \tag{38}$$

The first conjunct of the definition of this so-conditional is:

$$\forall \mathcal{M} \in \mathbf{L} : \mathrm{tr}(\mathcal{M},\ \mathrm{Front}(\mathrm{James},\ \mathrm{Tyr.}) \rightarrow \mathrm{Sees}(\mathrm{James},\ \mathrm{Tyr.})) \tag{39}$$

All models that make the antecedent Front(James, Tyr.) false make the material conditional true. We therefore only need to consider those models that make the antecedent true. By construction there are such models, so that the second conjunct of the definition (36) of the truth of (38) holds. Do all such models also make the consequent Sees(James, Tyr.) true? Well, reflected sunlight falls in the eyes of James, who stands in a typically Jurassic landscape, and the light forms an image on his retina after being refracted through the lens of his eyes ($\mathrm{e}_{\mathrm{James}}$), reflected by the reptile's body-armour, of an intensity which lies far above the sensitivity-threshold of the eye. This makes the consequent true. Then the so-conditional also comes out True, due to (37).

Similar arguments and considerations pertain to the other so-conditionals.[31]

We now predict that all modal talk *in science* can be saved in similar fashion by means of definitions (29) and relevant accessibility relations. Those who disagree are obliged to provide counter-examples, we submit. Until and unless such counter-examples surface, CE can claim to save all the relevant linguistic phenomena.

[c] Since modal propositions are now on a par with all other scientific propositions, they fall unproblematically under the purview of the epistemic policy of CE: believe only those accepted modal propositions (i.e. modal propositions relying on an accepted scientific theory) that are about actual observables only and remain neutral *qua* belief about all other accepted modal propositions.

8 *Exitum*

We claim to have reached the Aims of this paper set out in the penultimate paragraph of the Introduction (Section 1). We claim to have showed that the problems raised for CE by Ladyman, Psillos and Musgrave, and the new problems raised by Monton & van Fraassen's response to Ladyman can all be solved within CE. We therefore also dare claim that Ladyman's conclusion ([2003], p. 855) that CE 'is untenable as a philosophy of science' is premature. Apart from these debates, we claim to have contributed to the philosophical discourse on observability in a scientifically informed manner, by means of our definition (24) and our Scientific Criterion (23). We have also sketched a rigorous approach to modality in science for every nominalist who likes the semantic view on scientific theories.

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[31] We cannot resist quoting van Fraassen ([1975], p. 248): 'Suppose we wish to give a thoroughly nominalist account of counterfactuals. Then we can say: the use of the subjunctive, as opposed to the indicative, form has as its only function to signal the theoretical commitment. Hence the subjunctive [would-] conditional is "true" exactly if the indicative conditional follows from the theory which the utterer accepts or advocates, plus certain true assumptions made in the context, and if the theory in question is stable.' Here 'stable' is circumscribed as 'at least never discredited by the phenomena' (*ibid.*). We claim to have made this precise above, in the framework of the semantic view—we have thus replaced the phrase 'follow', which signals syntactic allegiances, with semantic phrases (models making statements true) depending on which accessibility relation is chosen.

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